PHYSICS TOPICS FOR GENERAL SCIENCE EDUCATION

Lukáš Richterek
Palacký University Olomouc, Czech Republic

Discussing the content of education is a never-ending story. Naturally, with the development of sciences and our knowledge, we need to include new topics. Simultaneously, with limited lesson time, some other parts must be reduced or omitted. Thus, each generation has to inventory the most relevant topics for science education and define criteria for selecting the curriculum of STE(A)M subjects. It is generally better to cover fewer topics thoroughly, practising and consolidating basic facts and skills rather than many of them sketchily. At the introductory university or college level, we have many excellent and renowned textbooks e. g., (Halliday et al., 2007; Knight, 2017) or freely available textbooks and materials from OpenStax (Urone & Hinrichs, 2022), suggesting the selection of topics. One of the key questions for the physics education is the "physics for all", i.e., for lower and higher secondary education. In the Czech Republic, with ongoing revisions of the national curricula, it is a significant question that may be relevant also for a larger audience in the international context. The considerations about the content for general education gained more attention from the parents and the public during the COVID-19 pandemic when parents supporting their children were more intensively confronted with the content of school curricula.

The content is developing evolutionally, as documented via textbooks, which remain a key source for teachers. As shown by (Holbrow, 2008), while 19th-century textbooks were more concentrated on descriptive physics with demonstration or measuring apparatus, along with a thorough description of their operation (such books can serve today as an encyclopedia of sometimes forgotten apparatus), during the 20th century there was a shift towards a higher level of abstraction and emphasizing principles and the unity of physics. According to the analysis (Keenahan & Keenahan, 2023), there also seemed to be a shift towards textbooks serving more effectively as resources for self-directed learning by students rather than as an aid to teachers in giving instruction. Besides, the authors and publishers try to make them more visually attractive. Both tendencies are undoubtedly even more observable in the case of online resources.

It is a part of the national tradition whether to teach science subjects separately (biology, chemistry, physics, etc.) or integrate them into one subject, e.g., science. Both possibilities have their advocates, therefore the national context plays an important role. As shown by (Holubová, 2024), from the central European view, physics should not be replaced by integrated science, despite the current shortage of physics teachers. Ideally, physics as a subject should support building skills considered important in the 21st century, namely communication and collaboration skills, creativity, and critical thinking. As briefly summarized by (Muller, 2010), "*physics is the liberal arts of high-technology*" with significant contributions to advances in new technologies that arise from theoretical breakthroughs. This was and sometimes still is reflected in the school curricula, that physics may start before other subjects like chemistry, which build on some physics concepts (Sheppard & Robbins, 2003). Based on the experience with teaching live-sciences majors, (Meredith & Redish, 2013) also point out, that two disciplines like

https://doi.org/10.33225/jbse/24.23.594

Journal of Baltic Science Education, Vol. 23, No. 4, 2024
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

physics and biology see the world differently (though, of course, there are always exceptions and overlays). In general, physicists stress reasoning from a few fundamental principles (usually mathematically formulated) and seek to build understanding from the simplest possible models paying much attention to constraints, such as conservation laws. Biologists deal more with real examples and emphasize structure-function relationships, being more descriptive and stressing less quantitative reasoning arising from "fundamental" abstract principles or simplified pictures. Biology (and sometimes also chemistry) students are typically less fond of mathematics and are reasonably comfortable with using equations to get quantitative results but are less familiar with using them as pieces of compressed information and insight into the world. This is even more true about the non-technically or art-oriented students. This brings other skills that are left to be developed within physics classes, like drawing inferences from equations or relations, connecting equations to physical meaning, understanding the implications of scaling and functional dependence, making estimates, and establishing a sense of scale; all this with appropriate respect to the level of education. Arguing for the importance of physics, we must also appreciate all other STEM subjects necessary for understanding our world's complexity and for the solution of its urgent problems, e.g., environmental (Lamanauskas, 2023; Lamanauskas & Malinauskienė, 2024).

The Ministry of Education, Youth and Sports of the Czech Republic recently left out e. g. Newton's laws and Ohm's law in physics, or the cell in biology from the obligatory national curriculum for lower secondary education with the rationale that those topics are difficult and abstract parts that are anyway not understood by most of the pupils which leads to the pure memorizing of the facts. Of course, teachers can take these topics, if they want, but it is not obligatory. This again opened more intensive debates over the curricular content. Undoubtedly, most schoolchildren will not intentionally apply Newton's laws in their lives (not realizing the laws work independently, whether we know them or not), and probably even some non-physics scientists cannot recite Newton's laws several years after graduating from their high schools. Although Ohm's law is a nice and rare example of an exact linear dependency in physics, the situation is probably similar. More pessimistically, most of what we try to pass on to pupils will probably be forgotten after some time, and, on the contrary, pupils will, if life leads them to it, acquire knowledge of what we did not give them (namely in their hobbies). From that point of view, should "physics for all" content be reviewed by non-physicists (e.g., biologists or chemists) and vice-versa?

The question is, whether the preparation for life is the only task of school. Speaking about general education, isn't one of the school's roles to spread out before pupils the panorama of the natural and human world that surrounds them? To help them join and appreciate human culture, where sciences, including physics, naturally belong? From that point of view, Newton's laws are part of a great revolution in history – they have shown us how rich and variable natural processes are governed by a small number of intelligible principles that form a coherent and logical whole that enables us to explain (among others) the mystery of celestial motions and the Earth's gravity. From that point of view, can we imagine a "history for all" curriculum without mentioning the French Revolution or a world literature review without Shakespeare? From this perspective, it provides an opportunity for "the power of story" (Willingham, 2021), and for the creative teachers, there are a lot of resources to make it with four Cs: Causality, Conflict, Complications, and a strong, interesting Character. Those components are natural parts of most great scientific discoveries.

Thus, we gradually come to the key question, what topics should be included in secondary-level physics as "physics for all"? We may look for inspiration in many textbooks intended for non-physicists, as examples from many let us mention (Crowell, 2016, Crowell, 2020; Knight, Jones, & Filed, 2022, March. 2002) or (Muller, 2010) intended as a physics for future world leaders. In its content we can find the following chapters:

- Energy and power, the physics of explosions.
- Atoms and heat.
- Gravity, force, and space (with subchapters on rockets, airplanes, Newton's 3rd law of Interactions).
- Nuclei and radioactivity, chain reactions, nuclear reactors, and atomic bombs.
- Electricity and magnetism.
- Waves (UFO's, earthquakes, music, light, invisible light).
- Quantum physics (lasers, transistors, electron microscopes, quantum computers).
- Elements of special and general relativity.
- The Universe (solar system, expanding universe, dark energy, and the beginning).

The problem is that such selection more or less, maybe in non-traditional order, covers more or less most of the topics we are traditionally teaching, not leaving many suggestions, what should be omitted. As mentioned below, the "devil is in details" – the content of those parts and, as often pointed out, in the way of exposition, used methods and activities. By the way, does anybody remember such topics being an important part of the pre-election debates?

https://doi.org/10.33225/jbse/24.23.594

Journal of Baltic Science Education, Vol. 23, No. 4, 2024
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

A specific problem is the inclusion of modern physics parts. Though this is a little bit relative term, usually it is understood as the physics of the 20th century, namely relativity, quantum and particle physics and the physics of microworld (which corresponds to the last three items in the list above). For example, the basis of special relativity theory is more than a century old and brings the spontaneous attention of the public, but relativistic effects like length contraction, time dilation, etc., are not supported by our everyday experience and intuition. Therefore, it is usually considered a difficult topic by most students and by many secondary school teachers (Özcan, 2017). There are many valuable attempts to make this topic more accessible and understandable at various levels of education e.g., (Alstein et al., 2021; Kersting & Blair, 2021). In Czech grammar schools, special relativity was included in the physics curriculum in the sixties, which was followed by an effort to evaluate the study materials and bring some innovations (e.g., omit the Lorentz transformations). Since that time, the content of the relativistic curriculum at most grammar schools has been reduced in lesson time, so now it roughly corresponds to a very simplified version of chapter 37 (Halliday et al., 2007) with fewer examples and problems. Though it may slightly vary in school curricula, the key topics are the same as introduced more than 50 years ago and covered in the most used textbook: space and time in classical mechanics, the historical development of SR, basic principles (postulates) of SR, the relativity of simultaneity, time dilation, length contraction, relativistic addition of velocities, basics of relativistic dynamics, mass-energy relation and Einstein's biography (another powerful story supported by TV series Genius and various biographies, locally we can recall his work at the Prague university in the years 1911–1912). Among others, the knowledge gained from studying the fundamentals of relativity is also applicable to teaching the fundamentals of quantum physics, atomic physics, and nuclear physics, it enables students to better understand the basic concepts of physics (energy, mass, time, simultaneity, etc.), that are not straightforwardly intuitive. The optimistic message provided by (Kočišová et al., 2024) is, that the performance of the Czech students in the test on special relativity has been nearly unchanged within the decades, despite some reduction of the lesson time.

Despite its importance, physics is typically unpopular as a subject, namely from the higher secondary level, where it is traditionally more based on math. Some authors emphasize the relevance of physics concepts in everyday life analogies (Das, 2015). The importance of scientific knowledge for survival in severe conditions was illustrated many times, from Verne's classical novel *The Mysterious Island* to a space Robinsonade version, Weir's novel and the following movie *The Martian*. Non-formally, these fictions are a unique kind of argument for education as life experience (knowledge, attitudes and skills) for life (cognition, consideration, behaviour), the idea formulated empathically by (Broks, 2014; Broks, 2020) as one of the top values to be globally developed today. As far as the content is concerned, we come to the conclusion that there are no answers for all concrete situations and needs. As technical details today are rapidly changing, more attention and value should be attributed to the understanding of general principles rather than particular details. This brings another advantage – the principles and laws have long-term validity (just remember the Newtonian laws published for the first time in 1687, Einstein's relativity only sets limits for their validity).

In the end, as put by (Brooks, 2014), our general aim, not only in STEM education, is to help our students to become creative, responsible, clever and honest people for our lives in the future. So, the content we choose should help them to develop general corresponding skills like critical thinking, creativity, communication and collaboration (Aberšek, 2023). When preparing future STEM teachers, we can assume that students choosing teacher preparation programmes are generally not worse in scientific performance and technical subjects (Hrouzková & Richterek, 2021). On the other hand, some students start to fully develop their basic reasoning abilities around their college years and need support even at that phase, especially in tasks demanding hypothetico-deductive thinking and correlation thinking.

JBSE traditionally supports raising the quality of physics education (Demkanin, 2023), which is a never-ending adventure. We know that as far back as the late 1800s, U.S. physics teachers expressed many of the same ideas about physics education reform that are advocated today; the situation in other sciences is highly probably analogical. According to (Holbrow, 2008), the physics teachers of 1899 complained of declining enrollments and lack of student motivation. Some asserted the need for hands-on experimentation, some urged that students be actively engaged. In every decade, there has been debate over the level of mathematics and mathematical preparation appropriate for beginning physics. Despite the widespread and long-standing support for the "inductive" method of instruction – referred to by various names such as "inquiry," "scientific practices," etc. – we still must support and advocate for the successful, long-lasting, and broad-based implementation of this method either in high school or college physics courses (Meltzer & Otero, 2015; Otero & Meltzer 2016), finding positive examples of these desired methods logistically and practically integrated into normal classroom practices. Besides repositories of shared

https://doi.org/10.33225/jbse/24.23.594

Journal of Baltic Science Education, Vol. 23, No. 4, 2024
ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

teaching materials like *Compadre Portal* (https://www.aapt.org/ComPADRE) maintained by the American Association of Physics Teachers, especially the sharing of experiences in teachers' communities seems to help to gradual steps in the desired direction (creating "islands of positive deviation"). From the Czech context, we can mention, e.g., every year conference *Physics Teachers' Inventions Fair* (https://vnuf.cz/index-en.html) or the *Heureka Project (Physics must be experienced!*) (https://kdf.mff.cuni.cz/heureka), in Lithuania, e.g., *National Scientific Practical Conferences* organized by *SMC Scientia Educologica* (http://gu.puslapiai.lt/conferences_en). In general, teaching STEM subjects is a complex mixture of practical and factual knowledge, conveying a deep understanding of fundamental principles and developing the appreciation of, and facility with, the use of scientific methods. To some extent, the teacher can choose the right proportions (not leaving any part) and the corresponding content and topics in some consistent and logical order appropriate to the level of the students. Naturally, the teachers should be comfortable with the topics, ideally positively interested in them; nobody can expect that the teacher is going to raise the interest of students if he or she does not like it and has no basic interest in it. Therefore, we should always keep some disposable lesson time for the teachers to go through the content they know and enjoy. Then we can meet the case that effective teachers can connect personally with students and organize the material in a way that makes it interesting and easy to understand (Willingham, 2021).

This year we have lost *Daniel Kahneman* (March 5, 1934 – March 27, 2024), an Israeli-American psychologist best known for his work on the psychology of judgment and decision-making as well as behavioural economics, for which he was awarded the 2002 Nobel Memorial Prize in Economic Sciences together with Vernon L. Smith. In the educational context, he is known for his bestsellers (Kahneman, 2011; Kahneman, Sibony & Sunstein, 2021). According to him, our thinking consists of 2 systems. ***System 1*** is fast, automatic, and intuitive, operating with little to no effort. This mode of thinking allows us to make quick decisions and judgments based on patterns and experiences. In contrast, ***System 2*** is slow, deliberate, and conscious, requiring intentional effort. This type of thinking is used for complex problem-solving and analytical tasks where more thought and consideration are necessary. More often than we would like to admit, we rely on System 1, which can generate surprisingly complex patterns of ideas, but only the slower System 2 can construct thoughts in an orderly series of steps, consider probability, etc. From this point of view, within STEM education our goal is clear – to support System 2 and the habit of using it more often. Alternatively, as put by (Willingham, 2021), we should review each content and lesson plan in terms of *what the student is likely to think about*. As memory is the residue of thought, we must ensure that students are thinking about the meaning of the material and content of our lessons (at least most of them).

In other words, as pointed out by (Rovelli, 2020), this is a possible lesson from our endeavour to understand the interpretation of quantum mechanics. The best way to learn is to interact with the world while seeking to understand it, readjusting our mental schemes to what we encounter and find, and trying to distinguish the signal and the noise (Silver, 2012). This conclusion is valid not only for science education.

References

Aberšek, B. (2023). A historical understanding of how science works. *Journal of Baltic Science Education*, *22*(6), 952–955. https://doi.org/10.33225/jbse/23.22.952

Alstein, P., Krijtenburg-Lewerissa, K., & van Joolingen, W. R. (2021). Teaching and learning special relativity theory in secondary and lower undergraduate education: A literature review. *Physical Review Physics Education Research*, *17*(2), Article 023101. https://doi.org/10.1103/PhysRevPhysEducRes.17.023101

Broks, A. (2014). Scientific thinking – the backbone of modern science and technology education. *Journal of Baltic Science Education, 13*(6), 764–766. https://doi.org/10.33225/jbse/14.13.764

Broks, A. (2020). General remarks on basic actualities within our life and education during first 20 years of 21st century. *Journal of Baltic Science Education*, *19*(5), 692–695. https://doi.org/10.33225/jbse/20.19.692

Demkanin, P. (2023). Raising quality of physics education: contribution of JBSE over the past issues. *Journal of Baltic Science Education*, *22*(5), 744–748. https://doi.org/10.33225/jbse/23.22.744

Crowell, B. (2016). *Relativity for Poets*. http://www.lightandmatter.com/poets/

Crowell, B. (2020). *Light and matter*. Introductory physics for students majoring in the life sciences. http://www.lightandmatter.com/lm

Das, K. K. (2015). *The quantum rules. How the laws of physics explain love, success, and everyday life*. Skyhorse Publishing.

Halliday, D., Resnick, R., & Walker, J. (2007). *Fundamentals of physics*. Wiley.

Holbrow, C. H. (2008). Archaeology of a bookstack: Some major introductory physics texts of the last 150 years. *Physics Today*, *52*(3), 50–56. https://doi.org/10.1063/1.882613

Holubová, R. (2024). Does generation Z (and Alpha) need physics as a separate school subject? *Journal of Physics: Conference Series*, *2715*(1), Article 012003. https://doi.org/10.1088/1742-6596/2715/1/012003

ISSN 1648–3898 /Print/
ISSN 2538–7138 /Online/

Hrouzková, T., & Richterek, L. (2021). Lawson classroom test of scientific reasoning at entrance university level. In V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 74–85). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.74

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.

Kahneman, D., Sibony, O., & Sunstein, C. R. (2021). *Noise: A flaw in human judgment.* Little, Brown Spark.

Keenahan, J., Carroll, M., & Keenahan, D. (2023). The evolution of physics textbooks used in Ireland 1860–2022. *Physics Education*, *58*(2), Article 025020. https://doi.org/10.1088/1361-6552/acb032

Kersting, M., & Blair, D. (Ed.). (2021). *Teaching Einsteinian physics in schools.* Routledge.

Knight, R. D. (2004). *Five easy lessons: Strategies for successful physics teaching.* Addison Wesley.

Knight, R. D. (2017). *Physics for scientists and engineers: A strategic approach with modern physics*. Pearson Education.

Knight, R. D., Jones, B., & Filed, S. (2022). *University physics for the life sciences*. Pearson Education.

Kočišová, P., Richterek, L., & Slaměník, L. (2024). Special relativity at Czech schools: A half century comparison. *Journal of Physics: Conference Series*, *2750*(1), Article 012019. https://doi.org/10.1088/1742-6596/2750/1/012019

Lamanauskas, V. (2023). The importance of environmental education at an early age. *Journal of Baltic Science Education*, *22*(4), 564–567. https://doi.org/10.33225/jbse/23.22.564

Lamanauskas, V., & Malinauskienė, D. (2024). Ugdymas tvariam vystymuisi pradinėje mokykloje: būsimųjų pradinių klasių mokytojų pozicija [Education for sustainable development in primary school: The position of pre-service primary school teachers]. *Gamtamokslinis ugdymas bendrojo ugdymo mokykloje – 2024 / Natural Science Education in a Comprehensive School*, *30*(1), 30–40. https://doi.org/10.48127/gu/24.30.30

March, R. (2002). *Physics for poets* (5th edition). McGraw-Hill Science/Engineering/Math.

Meltzer, D. E., & Otero, V. K. (2015). A brief history of physics education in the United States. *American Journal of Physics*, *83*(5), 447–458. https://doi.org/10.1119/1.4902397

Meredith, D. C., & Redish, E. F. (2013). Reinventing physics for life-sciences majors. *Physics Today*, *66*(7), 38–43. https://doi.org/10.1063/PT.3.2046

Muller, R. A. (2010). *Physics and technology for future presidents: An introduction to the essential physics every world leader needs to know*. Princeton University Press.

Otero, V. K., & Meltzer, D. E. (2016). 100 years of attempts to transform physics education. *The Physics Teacher*, *54*(9), 523–527. https://doi.org/10.1119/1.4967888

Özcan, Ö. (2017). Examining the students' understanding level towards the concepts of special theory of relativity. *Problems of Education in the 21st Century*, *75*(3), 263–269. http://dx.doi.org/10.33225/pec/17.75.263

Sheppard, K., & Robbins, D. M. (2003). Physics was once first and was once for all. *The Physics Teacher*, *41*(7), 420–424. https://doi.org/10.1119/1.1616483

Rovelli, C. (2020). *Helgoland. Making sense of the quantum revolution*. Adelphi Edizioni SPA.

Silver, N. (2012). *The signal and the noise: Why so many predictions fail – but some don't*. The Penguin Press.

Urone, P. P., & Hinrichs, R. (2022). *College physics 2e*. OpenStax. https://openstax.org/details/books/college-physics-2e

Willingham, D. T. (2021). *Why don't students like school? A cognitive scientist answers questions about how the mind works and what it means for your classroom*. Jossey-Bass.

Lukáš Richterek

Mgr, PhD, Assistant Lecturer, Department of Experimental Physics, Faculty of Science, Palacký University Olomouc, 17. listopadu 1192/12, CZ-771 46 Olomouc, Czech Republic.
E-mail: lukas.richterek@upol.cz
Website: https://muj.optol.cz/~richterek
ORCID: https://orcid.org/0000-0002-2252-007X

https://doi.org/10.33225/jbse/24.23.594